BOONTON

HIGH ACCURACY AM-FM MEASUREMENTS WITH THE BOONTON 82AD MODULATION METER

APPLICATIONS NOTE #19

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INTRODUCTION

The Boonton Model 82AD is an accurate and easy-to-use modulation meter. However, to achieve the highest accuracy it may be necessary to interpret carefully the displayed measurements. The purpose of this applications note is to describe these interpretations.

Section I covers the effect that noise and spurious responses can have on both AM and FM modulation measurements. Section II describes conditions that affect only AM measurements, and Section III covers FM measurements. Miscellaneous applications are described in Section IV.

An appendix in Section V covers the design of the linear-active detector that is used in the 82AD and derives its calibration procedure.

SECTION I

FACTORS AFFECTING ACCURACY

1.1 NOISE

The 82AD has been designed to minimize internally generated noise. However, some small noise residuals must be considered for most accurate AM and FM measurements. The residual AM and FM data shown in Figures 1-1 and 1-2 was measured by driving the 82AD with a crystal controlled source at spot frequencies between 10 and 1200 MHz and levels between +10 and -20 dBm. The major source of noise, however, is usually not the internally generated noise, but the noise of the signal that is connected to the 82AD RF input.

The definitions of AM and FM modulation are stated in terms of the peak amplitude of the modulating signal. An instrument which measures modulation must therefore measure the peak or peaks of the recovered modulation waveform. This is why noise modulation must be considered in accurate modulation measurements. The peak amplitude of the composite signal is the sum of the peak amplitude of the desired signal plus the peak amplitude of the noise signal. Note that we are dealing with *peak* amplitudes. The crest-factor for noise in the 82AD circuits is about three to one, which means that the front panel display of the 82AD will read about three times as much as an rms detector monitoring the AF OUT connector with only noise modulation present.

At this point it should be noted that if the signal source under test is the major source of noise modulation, then the peak reading of the 82AD is in fact the "true" peak modulation of the signal source. For example, assume an FM carrier at 200 MHz with precisely 5 kHz deviation and 10 Hz rms noise modulation being measured with an 82AD with 3 kHz low-pass filtering. From Figure 1-1, the residual FM of the 82AD is approximately 3.5 Hz rms, or 10.5 Hz peak. The 82AD indication is then:

Modulation	+	Carrier Noise	+	82AD Noise	=	82AD indication
5.00	+	0.03	+	0.01	=	5.04 kHz

If the 5 kHz modulation component is now removed (by turning off the modulator), the 82AD will read 0.04 kHz deviation. The error in the measurement of true deviation caused by internal noise is not 0.8%, as it would seem, but only 0.2%.

The above example is a typical 82AD application. The point to remember is that, since the 82AD peak detectors are accurate over the entire displayed range, residuals may be subtracted in order to enhance measurement accuracy. This is not true of meters using passive peak detectors. Passive diode peak detectors approach rms detection for small signals such as residual noise, and thus corrections cannot be made easily.

1-2. SPURIOUS RESPONSES

All frequency converters have unwanted or spurious responses due to the nonlinear nature of mixing. The 82AD converts frequency by using a sampler, which is very linear and produces very few spurious responses in the usual sense. There are, however, a few points to remember when applying a sampling instrument like the 82AD. (Refer to the 82AD Instruction Manual for a description of the sampler operation.)

The internal oscillator of the 82AD sweeps from 10 to 20 MHz while searching. By converting this swept local oscillator into a very narrow sampling pulse, all harmonics (up to about 200) are generated. This provides coverage to carrier frequencies beyond 1.2 GHz. For example, if the local oscillator is swept from 10 to 20 MHz, the second harmonic is moving from 20 to 40 MHz, and the 10th harmonic is moving from 100 to 200 MHz.

This means that if two or more signals are simultaneously present at the RF input connector of the 82AD, they could both be converted into the IF pass-band. This is not generally a problem if the signals are harmonically related since the harmonics are converted in the proper phase relationship. However, if no phase continuity exists, the signals will be converted as different tones in the IF passband.

For example, assume two input signals, the larger at 100 MHz and the smaller at 504 MHz. The local oscillator might lock at 10.1 MHz (101 MHz at the tenth

harmonic) to produce a 1 MHz IF. The 50th harmonic is at 505 MHz which converts the 504 MHz carrier to 1 MHz as well. Since the two RF signals are not phase coherent, a low frequency beat will occur at the IF and produce spurious AM and FM indications. The solution here is to filter the offending signal at the carrier frequency using a low-pass or band-pass filter. If the IF beat frequency is high enough, baseband filtering can eliminate the problem. For example, if the beat note is at 100 kHz, then selecting the 15 kHz low-pass filter will eliminate the tone. Figure 1-3 shows how the sampler converts harmonics in phase to reproduce a 10 MHz square wave at the 1 MHz IF. Figure 1-4 shows an FM signal at the AF OUT connector with a spurious tone superimposed.

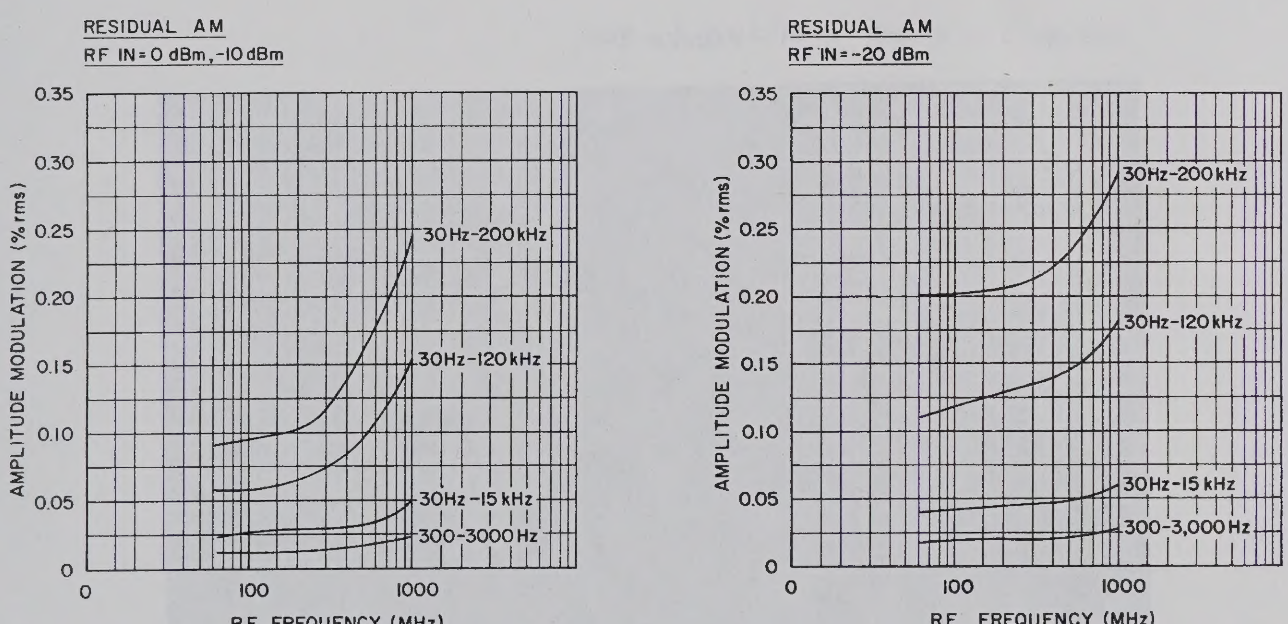

Figure 1-1.

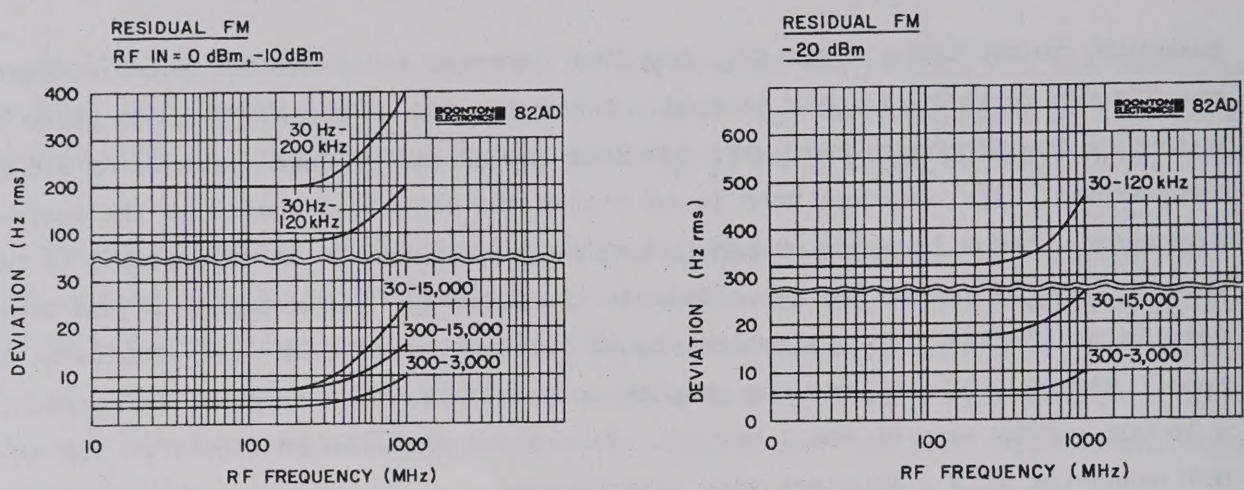

Figure 1-2.

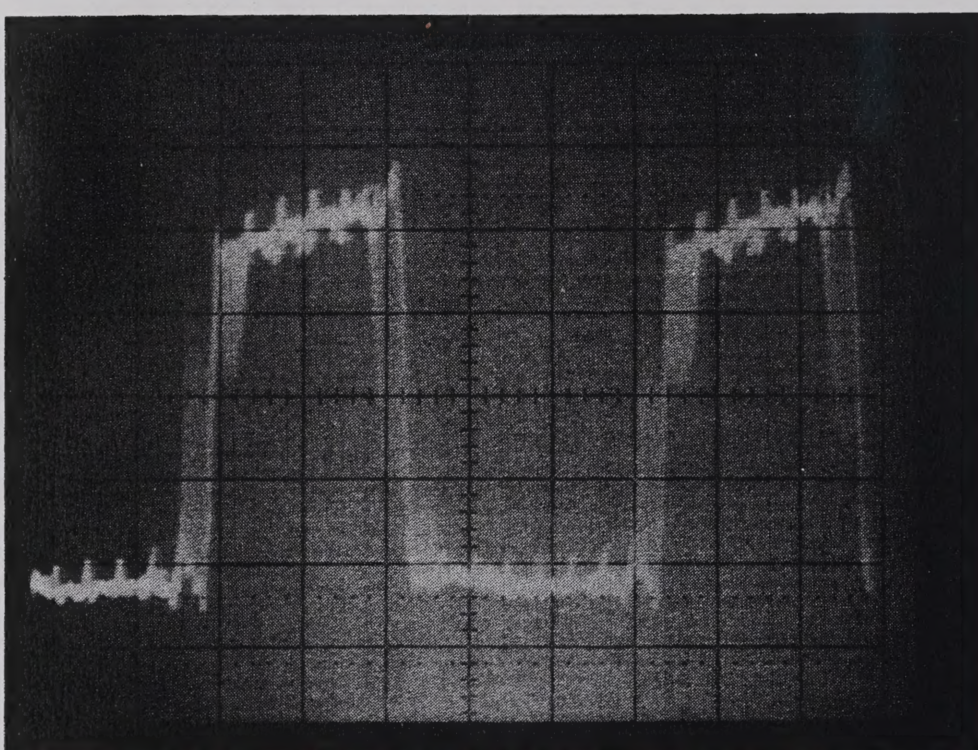

Figure 1-3. Sampler Square Wave Response
Vert. 1 Volt/Div. Horiz. -.2 µs/Div.

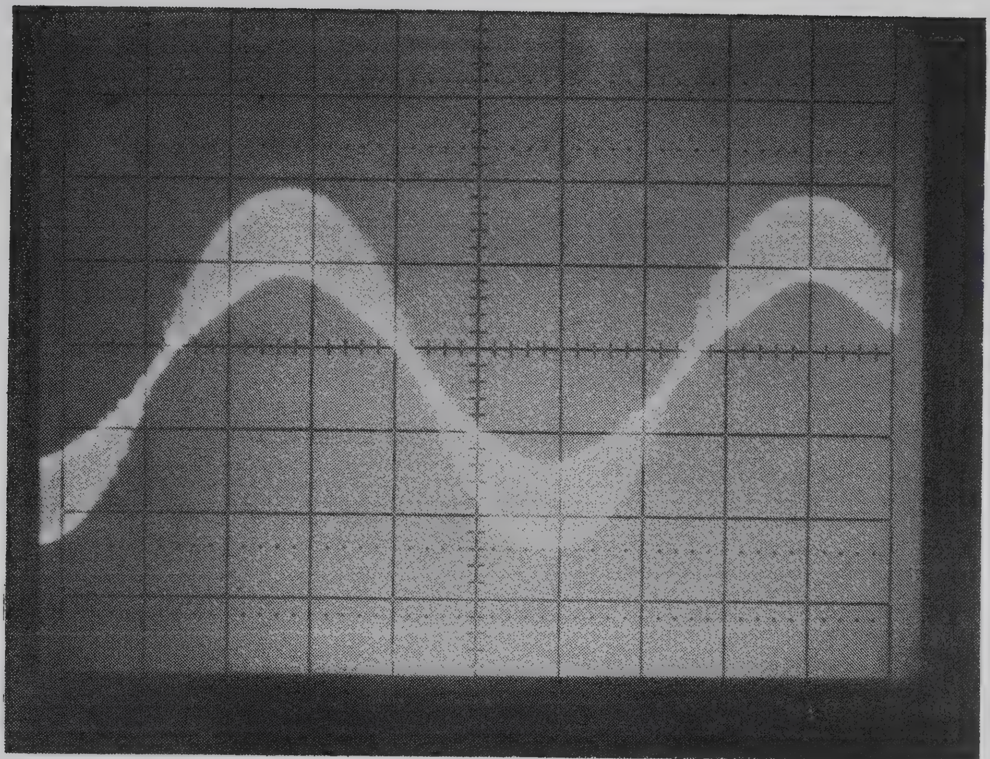

Figure 1-4. Spurious Response

Vert. 1 Volt/Div. Horiz 0.2 ms/Div.

SECTION II

AM MEASUREMENTS

The 82AD is one of the most accurate amplitude modulation measurement instruments available. The unprecedented accuracy is due to careful design of the amplitude modulation amplifier-detector system and to very accurate peak detector circuits. A description of the linear-active detector used in the 82AD can be found in the appendix of this Applications Note.

2-1. AMPLITUDE MODULATION DETECTOR LINEARITY

The linearity of the AM detector system used in the 82AD may be measured in two different ways. The first is what might be termed the "static linearity". The measurement is made as follows:

a. Connect equipment as shown in Figure 2-1.
b. Set the 102C Signal Generator to 30 MHz, CW, +10 dBm.
c. Set the 103C Signal Generator to 15.5 MHz, CW, 0 dBm.
d. Set the 82AD controls as shown.
e. Adjust the piston attenuator to 0.00 dB and the 82AD level control until the DVM reads 2.000 Vdc.
f. Change the piston attenuator to -10.00 dB and record the DVM reading.
g. Repeat (e.) for -20.00, -30.00, and -40.00 dB.

The data points are the ac to dc transfer characteristic of the 82AD AM measurement channel (including amplifiers and front-end). AM performance can be inferred from the above characteristic, although phase modulation due to detector non-linearity is not obvious.

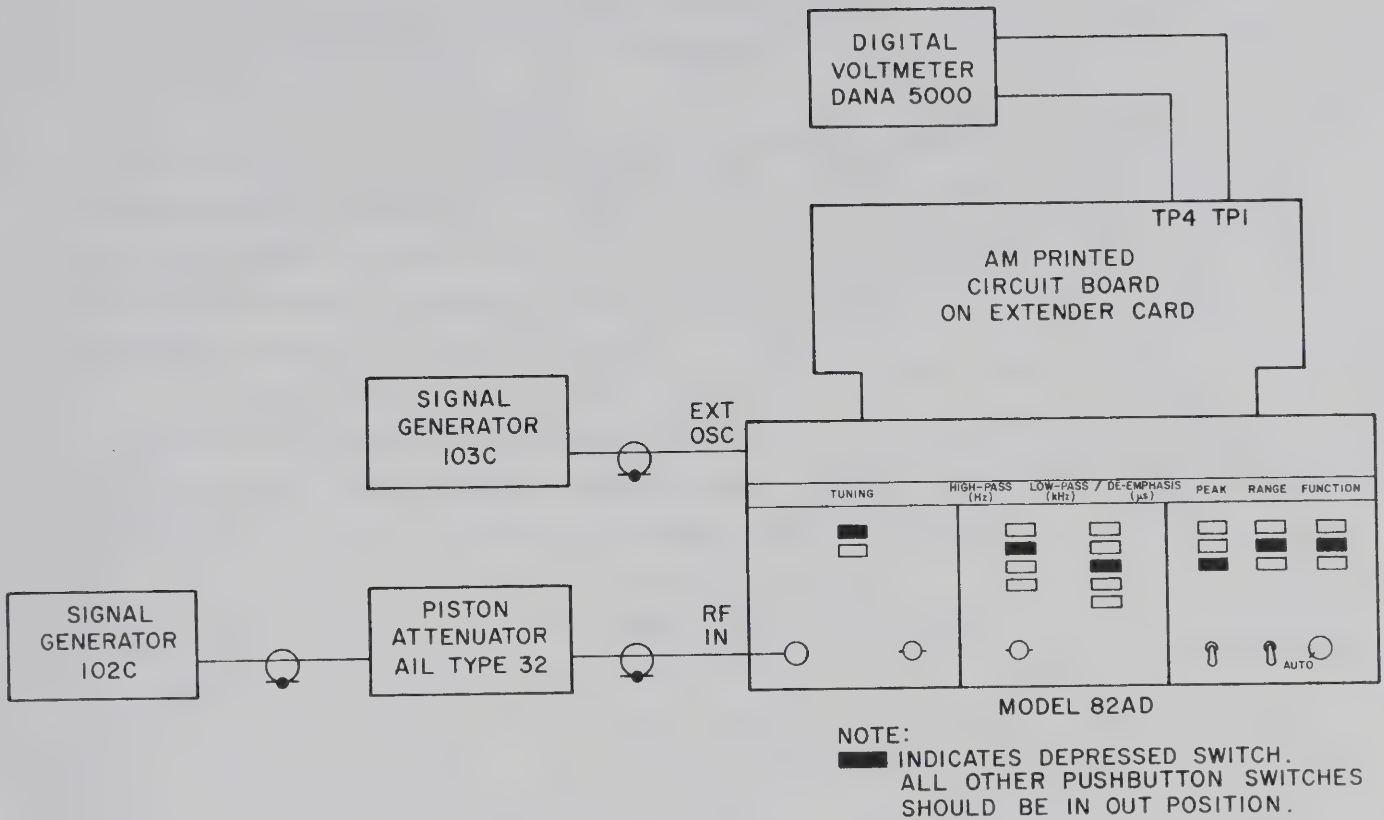

Figure 2-1.

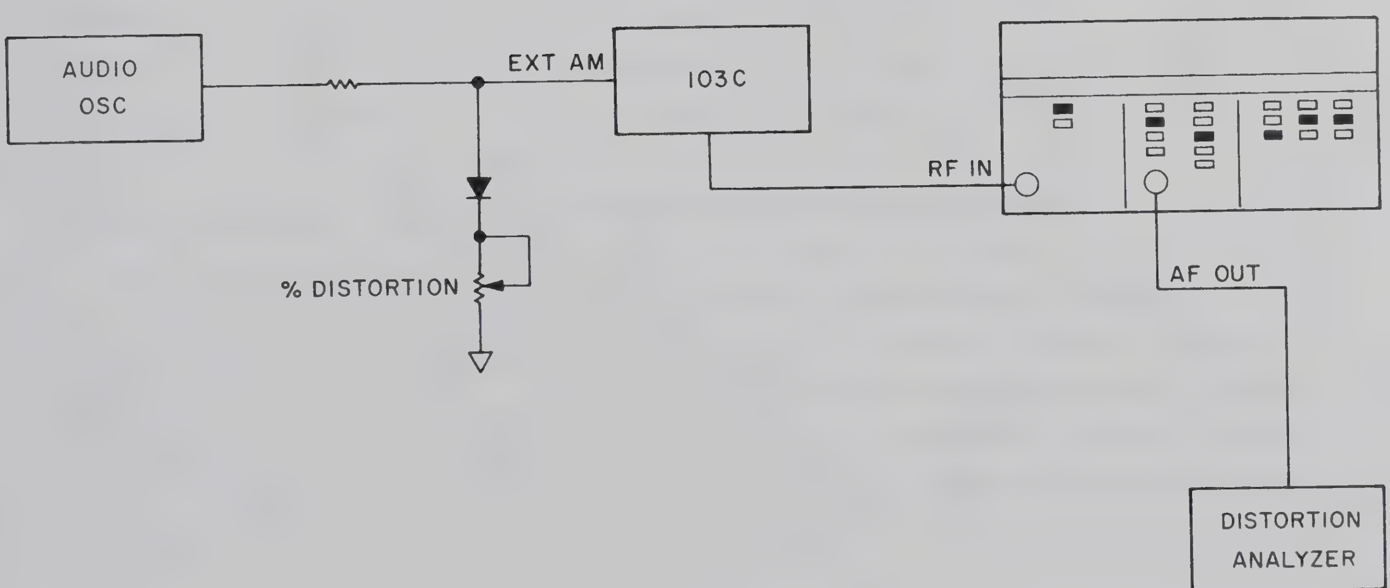

Figure 2-2.

Another more sensitive method measures the change in slope of the detector system. The measurement is made as follows:

a. Connect the equipment as shown in Figure 2-1.
b. Set the 102C generator to 30 MHz, +10 dBm, and 50% AM at a 1 kHz mod rate.
c. Set the 103C generator to 15.5 MHz, 0 dBm, and CW.
d. Set the piston attenuator to 0.00 dB.
e. Set the 82AD controls as shown.
f. Adjust the 82AD level control for a reading of 20.00 within 5%.
g. Adjust the AM modulation level for a reading of 2.000 Vac.
h. Change the piston attenuator to -10.00 dB and record the DVM reading.
i. Repeat (g.) for -20.00, -30.00, and -40.00 dB.

The data points taken above give the slope of the transfer function of the AM measurement channel. Table 2-1 gives typical data for a production 82AD.

Table 2-1.

ATTENUATION	AC DVM	IDEAL	SLOPE ERROR (%)	APPROX. % AM (TROUGH)
0.00	2.0005	---	0.0	--
-10.00	0.6331	0.6326	0.08	37
-20.00	0.1997	0.2001	-0.17	80
-30.00	0.0628	0.06326	-0.73	94
-40.00	0.0197	0.0200	-1.50	98

By expanding the change of slope data using the incremental form of Taylor's series, the harmonic distortion terms can be computed. The second harmonic term predominates with an amplitude equal to 1/4 of the change in slope. The third harmonic may be ignored since it is only 1/6 of the amplitude of the second harmonic. For the worst case combination of fundamental and second harmonic, the 82AD AM system error will be maximum and equal to the amplitude of the second harmonic term. For the data above the 82AD will produce an error of 0.18% at 94% AM. Detection errors will be less than 0.1% up to 80% AM.

2-2. ENVELOPE DISTORTION

The definition of AM is normally stated in terms of the fundamental component of the modulation frequency. In practice, the envelope of an amplitude modulated wave usually contains harmonics of the modulation frequency. To obtain the lowest errors in indicated AM using a linear-active detector in the 82AD, the envelope distortion should be as low as possible.

Odd harmonic distortion will tend to affect both the peaks and the troughs of the waveform. This type of distortion does not affect the "average" value of the unmodulated carrier. Therefore the automatic gain control (AGC) in the 82AD will operate without offset and the indicated "+" and "-" peaks will agree very well with peaks and troughs as displayed on an oscilloscope.

Even harmonic distortion, on the other hand, causes average value changes in the modulated carrier level. The AGC circuits in the 82AD remove this dc term and indicate substantial differences in the "+" and "-" peak readings. Just how the indicated AM compares with the peaks and troughs as displayed on an oscilloscope is a function of the amplitude and phase of the distortion components (see the appendix). The derivations in the appendix show that when the second harmonic component is cosine related to the fundamental, the average value of the modulated carrier is not the same as the average value of the unmodulated carrier by an amount equal to the amplitude of the second harmonic component. The 82AD responds to this type of distortion by modifying AM channel gain by an amount necessary to remove this dc component. This in turn causes the peak average indication to be in error.

One of the peak readings is correct depending on which peak is distorted. If the positive peak is compressed, the 82AD reads correctly in the "-" peak mode and the "+" peak reads lower. The difference in the two numbers is the approximate distortion in percent. Conversely, if the trough is distorted, the 82AD reads correctly in the "+" peak mode and the "-" peak reads lower. The difference again is the approximate distortion in percent.

The experimental setup shown in Figure 2-2 was used to evaluate 82AD response with various amounts of second harmonic distortion. The results tabulated in Table 2-2 show the excellent agreement between the peak difference and the measured distortion.

TABLE 2-2.

% DISTORTION	PK-PK/2	+ PEAK	- PEAK	Δ PEAK
3.8%	49.9	48.2	51.6	3.4%
5.1%	49.7	47.2	52.1	4.9%
6.8%	50.2	46.8	53.5	6.7%
10.0%	49.9	45.0	54.7	9.7%
13.0%	50.6	44.1	56.9	12.8%

In applications where appreciable envelope distortion is normal, baseband filter selection is important. Care should be taken to insure adequate measurement bandwidth to accurately reproduce envelope harmonics. If the characteristics of the envelope are uncertain, an oscilloscope connected to the AF OUT connector is helpful in determining the proper 82AD control settings.

When digital signals or non-sinusoidal signals are measured, an oscilloscope may be required to determine proper filter selection. The baseband filters used in the 82AD have Butterworth response and modest overshoot occurs when square-wave signals are applied to the audio sub-system. Wideband filters should be selected to eliminate errors when this type of measurement is made.

Any modulation signals which have a discontinuous character (such as sinusoids synthesized using digital techniques) may produce unexpected readings if a perturbation occurs at or near the peak of the modulating signal. Again, judicious selection of post-detection filtering can remove possible errors in readings.

2-3. HIGH PERCENTAGE AM

Difficulties may be experienced with the 82AD when attempting to measure AM modulations approaching 100%.

The 82AD automatically searches for, and locks on to, the highest carrier level between 10 MHz and 1.2 GHz. If this carrier is AM-modulated the carrier tends to disappear in the troughs of modulation as the percentage AM approaches 100%. This causes the 82AD to lose lock and start a search for a higher level carrier.

The point at which frequency lock is lost is a function of carrier frequency and level. Worst case occurs at low frequencies and low levels where lock can be lost at approximately 93%. The situation improves to approximately 98% at high carrier frequencies and levels.

A simple field modification will allow accurate AM measurements to 100% and beyond at all carrier frequencies and levels. On the FM PC board A10, add a 0.1 μF, 20%, 50 V ceramic capacitor (BEC part number 224-268, AVX 3430-050E-104M, or equivalent) across R55 (10 kΩ) to slow the response of the lock detector circuits (Figure 2-3).

This change, however, can produce a false lock under very special conditions. If the 82AD is locked to a specific carrier frequency (for example, 200 MHz) and the 82AD input frequency is quickly changed in less than 10 ms to a new frequency which is precisely one-half of the previous frequency (in our example, to 100 MHz), and if the new carrier has substantial second harmonic distortion, the 82AD will lock on to the second harmonic (in our example, 200 MHz). This situation will not occur at power-up or when a signal is initially applied to the 82AD. The 82AD must have been previously locked, and the signal quickly changed to one-half of the original frequency for this fault to occur.

This modification allows accurate AM measurement to 100% and beyond with only this one minor problem.

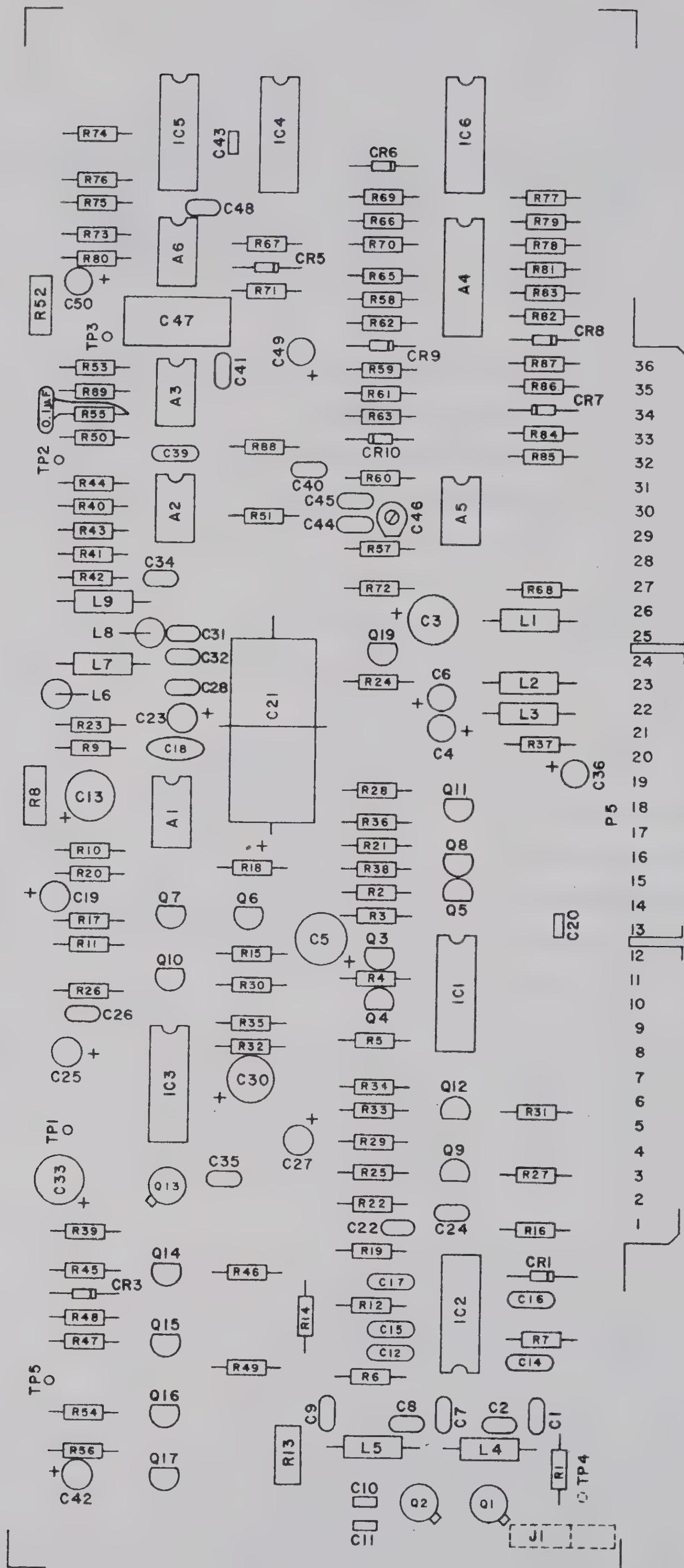
R74
IC5
C43
IC4
IC6
CR6
R76
R75
R69
R77
C48
R66
R79
R73
R67
R70
R78
R80
A6
CR5
R65
R81
C50
R71
R58
A4
R83
R52
C47
R62
R82
TP3
CR8
C49
CR9
R87
R53
C41
R59
36
R89
A3
R61
R86
35
0.1μF
R55
R63
CR7
34
R50
CR10
R84
33
TP2
C39
R88
R85
32
C40
R60
R44
31
C45
R40
A2
R51
C46
A5
30
C44
R43
29
R41
R57
R42
C34
28
R72
R68
27
L9
C3
L1
26
L8
C31
Q19
25
C32
24
L7
R24
C6
L2
23
C28
L6
C21
L3
22
C23
R23
21
C4
R37
20
R9
C18
C36
19
R8
C13
R28
Q11
P5
18
A1
R36
17
R21
Q8
16
R10
R18
R38
15
R20
C19
R2
14
Q7
Q6
Q5
R17
R3
C20
13
C5
Q3
12
R11
Q10
R15
R4
IC1
11
R26
R30
10
C26
Q4
R35
9
R5
R32
C25
8
IC3
C30
R34
Q12
7
R33
6
R31
TP1
5
C27
R29
Q9
4
C35
R25
R27
3
C33
Q13
2
R22
C22
C24
R39
R16
1
R19
Q14
CR1
R45
R46
C17
CR3
C16
R12
R14
IC2
R48
Q15
C15
R7
R47
C12
C14
R49
TP5
R6
Q16
C9
C8
C2
R54
C7
C1
L5
L4
R56
R13
Q17
R1
TP4
C42
C10
Q2
Q1
C11
J1

Figure 2-3

SECTION III

FM MEASUREMENTS

The 82AD Modulation Meter is designed to make accurate modulation measurements at carrier frequencies from 10 to 1200 MHz. Deviations as low as 10 Hz and as high as 300 kHz can be measured at rates up to 200 kHz. The primary limitation on accuracy of FM indications is residual noise as discussed previously. Careful selection of post-detection filtering and subtraction of residuals can improve deviation accuracy well beyond the specified 2% of reading.

3-1. FM DETECTOR

The FM detector used in the 82AD is a pulse-counting discriminator, chosen for its excellent linearity. The circuit is simply a very accurate, low noise, one-shot multivibrator. The discriminator is triggered by a zero crossing of the IF signal and recovers after a fixed time delay (about 500 μs). By integrating the output of this circuit a measure of the instantaneous frequency is made.

3-2. DETECTOR LINEARITY

The linearity of the detector is determined by measuring the change in slope of the frequency-to-dc transfer function (Figure 3-1). The generator connected to the 82AD RF input is adjusted to 15 MHz, 0 dBm, and 3 kHz deviation at a 1 kHz rate. The generator connected to the EXT OSC connector on the rear panel is adjusted to 16 MHz, 0 dBm, and CW. The modulating signal of the RF generator is recovered while the EXT OSC signal is stepped from 15.70 to 16.30 MHz in 100 kHz increments so as to produce 300 kHz deviation around the 1 MHz IF frequency. The amplitude of the recovered signal is noted at each step and the slope of the transfer function is plotted. Figure 3-2 shows the slope characteristic of a typical 82AD.

The distortion produced by this non-linearity is determined by expanding the change in slope data using a Taylor's series. Thus, the distortion produced by the above detector is about 0.01% of 100 kHz deviation. As an example, the composite distortion measurement of a Boonton Model 102D and Model 82AD at 100 MHz, 0 dBm, and 100 kHz

deviation at a 1 kHz rate is about 0.05% THD (principally 2nd harmonic).

3-3. RESIDUAL FM MEASUREMENTS

Carrier noise measurements can be made with the 82AD using an external rms voltmeter such as the Boonton Model 93AD. The voltmeter is connected to the AF OUT connector and calibrated against the 82AD display using any fixed modulation near full-scale. Noise measurements are then made on an rms basis. Noise checks of the 82AD can be made by driving the 82AD from a crystal source at the desired frequency at a level greater than 100 mV and noting the rms indication. If a crystal source is not available, Figures 1-1 and 1-2 can be used to estimate the 82AD residuals.

Indicated FM increases linearly with base-band filter cut-frequency for a constant carrier noise pedestal. For instance, if the residual FM indicated on the 82AD in a 3 kHz measurement bandwidth is 10 Hz peak, then in a 15 kHz measurement bandwidth, the indication will be 50 Hz. When wide-band post-detection filters are required for a particular measurement, residual deviation can be quite large. In the above example the 82AD indication would be 667 Hz in a 200 kHz measurement bandwidth.

RMS measurement of modulation is recommended where large noise components are present. Although true peak information is lost, combined peak-rms measurements will give a good indication of the modulation without noise.

3-4. CARRIER SHIFT

The discussion of envelope distortion in AM measurements applies in a similar way to FM measurements. If a sizable amount of second harmonic distortion is present in the recovered audio signal, the average frequency of the modulated carrier is not the same as the average frequency of the unmodulated carrier. This effect is known as "carrier shift" and is present to some extent in all FM modulators. After lock occurs, the operation of the 82AD frequency lock loop (FLL) is similar to the operation of the AGC loop. The FLL will remove the dc terms from the recovered audio signal and indicate a difference in the "+" and "-" peak deviation. The amount of carrier shift is indicated in kHz by the difference in the "+" and "-" peak readings.

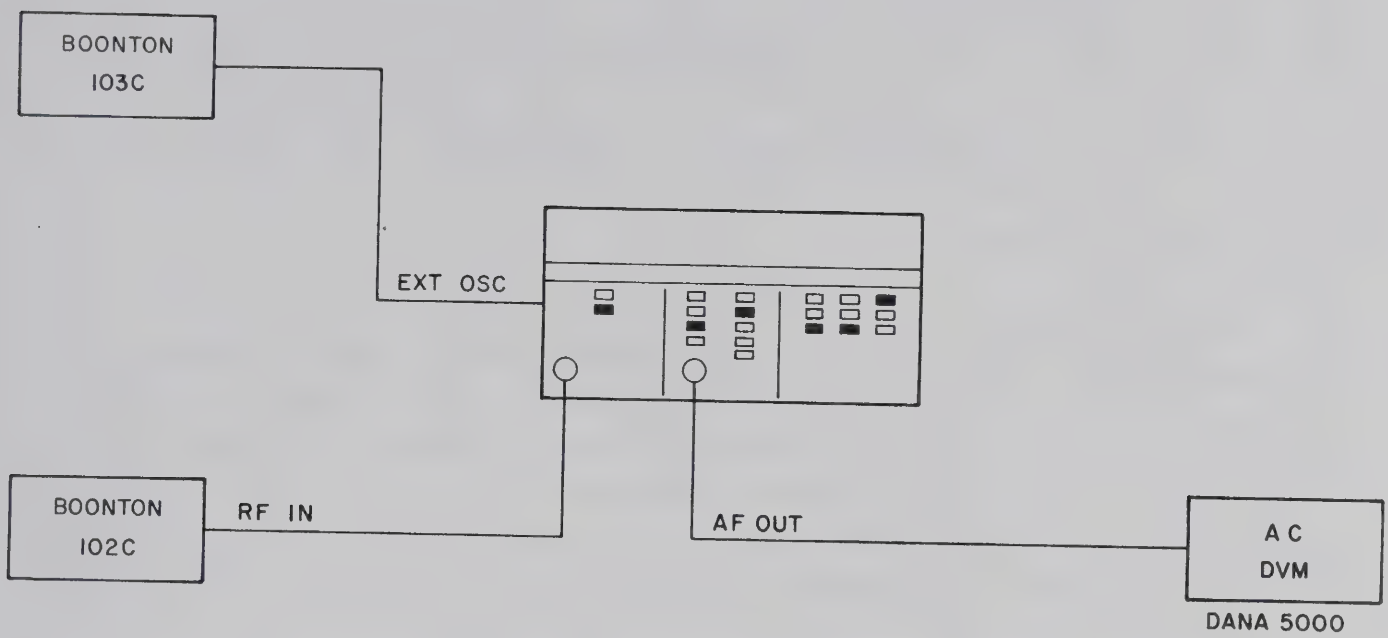

Figure 3-1

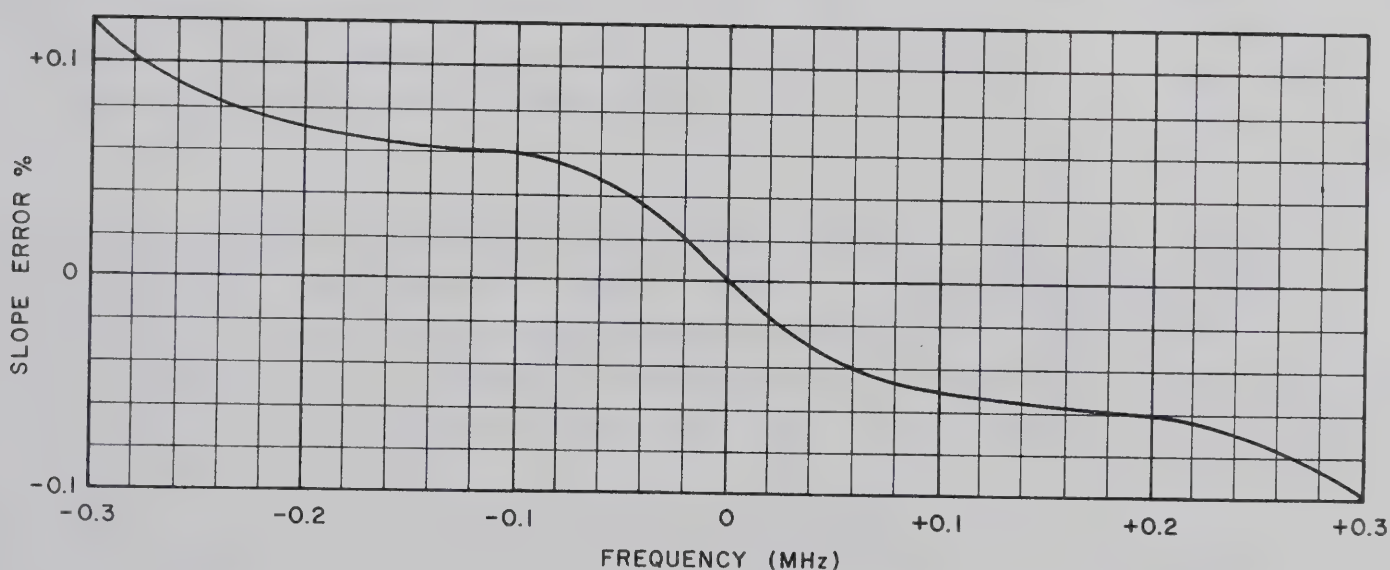

Figure 3-2

SECTION IV

MISCELLANEOUS APPLICATIONS

4-1. PHASE MODULATION

The 82AD is capable of measuring phase modulation (PM) when the 6 dB/OCT de-emphasis filter is selected. This active filter circuit provides the response necessary to produce constant deviation readings (in radians) for constant PM. The filter is useful over a frequency range of 300 Hz to about 10 kHz. Beyond these limits accuracy is degraded (See Figure 4-1). For example, if 2π radians of phase modulation is applied to the carrier, the 82AD will indicate 6.28 kHz deviation.

4-2. EXTERNAL OSCILLATOR MEASUREMENTS

Measurements beyond the normal frequency limits of the 82AD are possible using the external oscillator input connector. Figure 4-2 shows an equipment connection which will permit FM deviation measurements at 4.5 MHz. An external local oscillator at 5.5 MHz and 0 dBm is connected to the EXT OSC connector on the rear panel of the 82AD. EXT tuning is selected and other controls are set as desired. FM deviation should not exceed about 75 kHz to prevent sampler spurs from affecting the deviation indication.

The 82AD will not lock properly above 1.4 GHz due to search circuit sweep speed. Measurements can be made above 1.4 GHz by applying a low-noise signal to the EXT OSC connector. Any local oscillator frequency between 10 and 20 MHz which will produce a 1 MHz intermediate frequency is usable. However, for lowest noise the highest frequency should be used. The local oscillator frequency is calculated as follows:

$$f_{lo} = (f_{rf} + 1)/N$$

where f_{rf} is in MHz and N is any integer chosen such that f_{lo} is between 10 and 20 MHz.

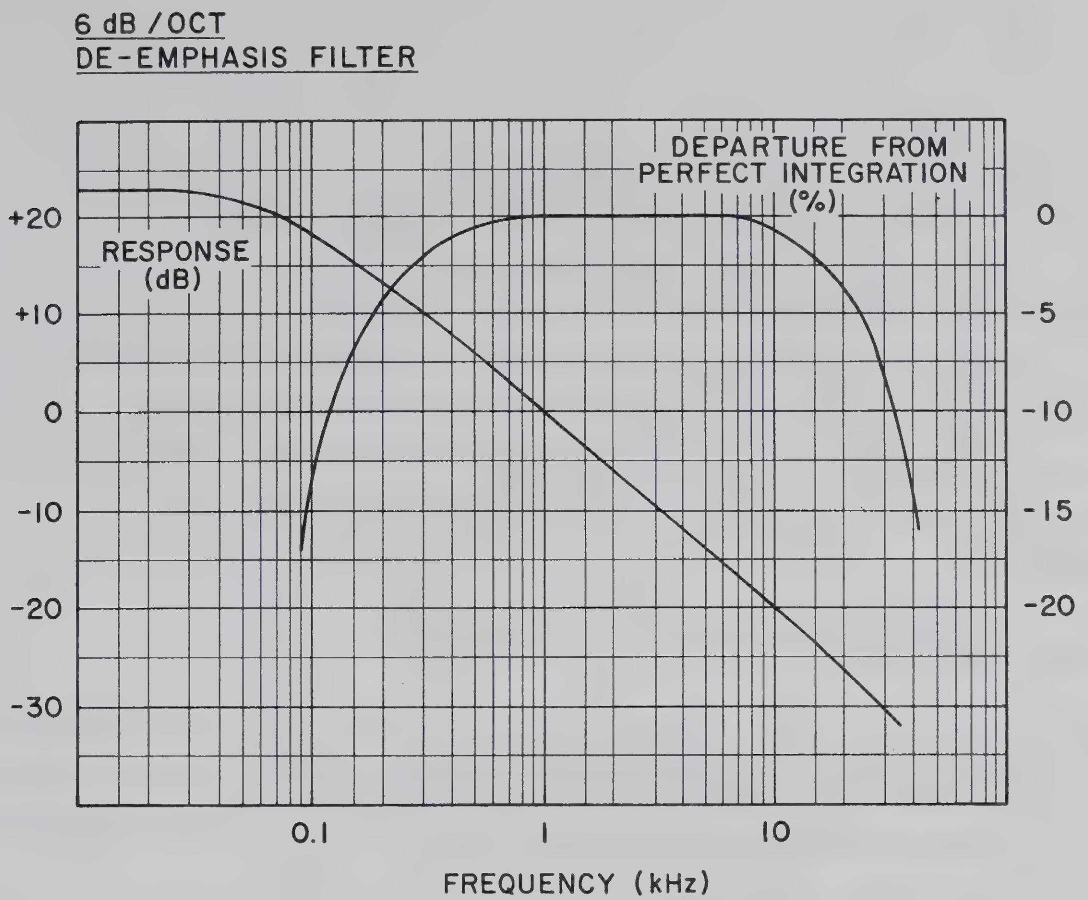

Figure 4-1

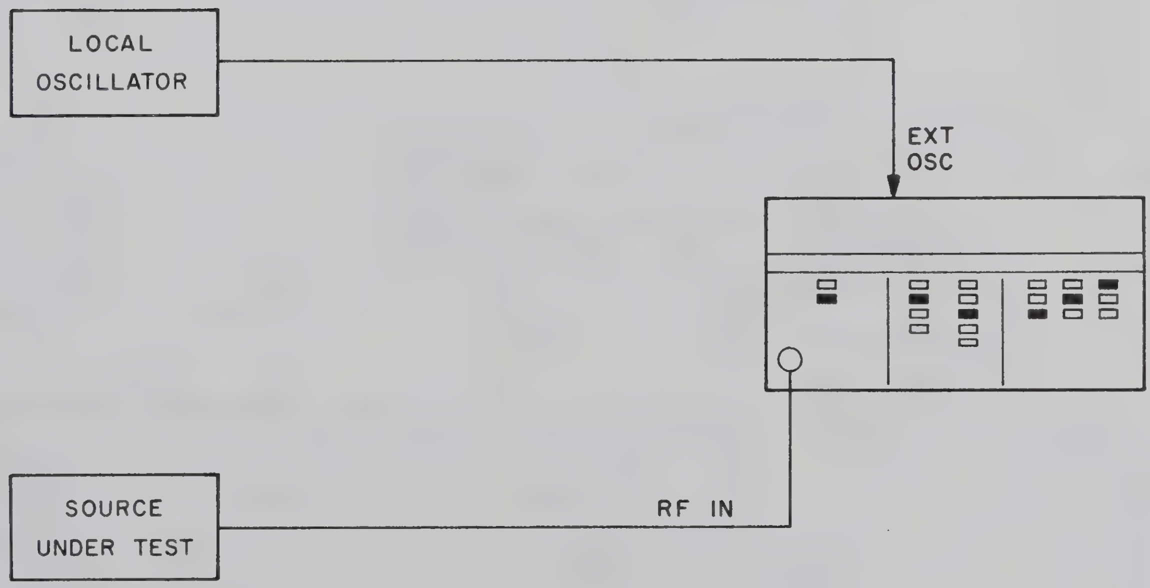

Figure 4-2

SECTION V

APPENDIX

This portion of the 82AD Applications Note contains pertinent information regarding the design and accuracy verification of the detectors used in the 82AD. The section relating to the linear active detector is a description of how the circuit was designed to achieve the unprecedented AM accuracy specifications of the 82AD.

5-1. THE LINEAR-ACTIVE DETECTOR

The heart of the AM measurement system is the linear-active detector. Conceptually the active form of the diode detector is a circuit connection where the offset and temperature dependent resistance terms of a diode can be absorbed in the feedback of a high-gain linear amplifier.

The forward voltage of a diode can be expressed as:

$$V = (NKT)\ln(I/I_o)/q + IR_S \tag{1}$$

where N (ideality factor) = a number from 1 to 4

- K = Boltzman's constant = 1.3806×10^{-23}
- q = Unit charge = 1.652×10^{-19}
- T = Temperature in Kelvin degrees
- I_o = Diode saturation current
- R_S = Saturation resistance of diode
- I = Diode current

This expression can be differentiated to determine an equivalent diode resistance:

$$r = NKT/q(I + I_o) + R_S \tag{2}$$

When the diode is placed in the feedback network of a high-gain amplifier (Figure 5-1) the output voltage of the stage becomes:

$$E_{out} = \frac{- I_{in} R_f R_{in} (A R_f - r)}{(R_f + r) (R_f - R_{in}) - R_{in}(A R_f - r)} \tag{3}$$

This expression can be evaluated for the limiting cases of r approaching R_s and infinity. For $r = R_s$:

$$E_{out} = - I_{in} (R_f + R_s/A) \tag{4}$$

For r approaching infinity:

$$E_{out} = I_{in} R_{in} \tag{5}$$

Equations (4) and (5) show that at high currents the output waveform is very linear, but at low currents the output voltage actually reverses phase and approaches the amplifier input voltage.

At this point it is well to consider the amplifier and diode types which will produce the optimum detector circuit.

In order to approximate the perfect diode, the offset voltage and the ideality factor should be minimized.

A Shottky type diode fulfills this requirement nicely. Offset voltages of from 0.3 to 0.4 volts are possible and the ideality factor is very close to 1, typically from 1.05 to 1.1. The amplifier circuit should have a high input impedance to avoid shunting current away from the feedback path and as much gain as possible consistent with loop stability.

It should be noted, however, that when the input current is zero, both diodes are open and the diode capacitance will then control the loop gain. Since the feedback path is effectively open, the "commutating gain" of the amplifier can be made arbitrarily high. Stability can still be maintained so long as loop gain drops when the diodes begin to conduct. A circuit configuration which provides this characteristic is a transconductance amplifier, e.g., one that converts a voltage into a current (Figure 5-2).

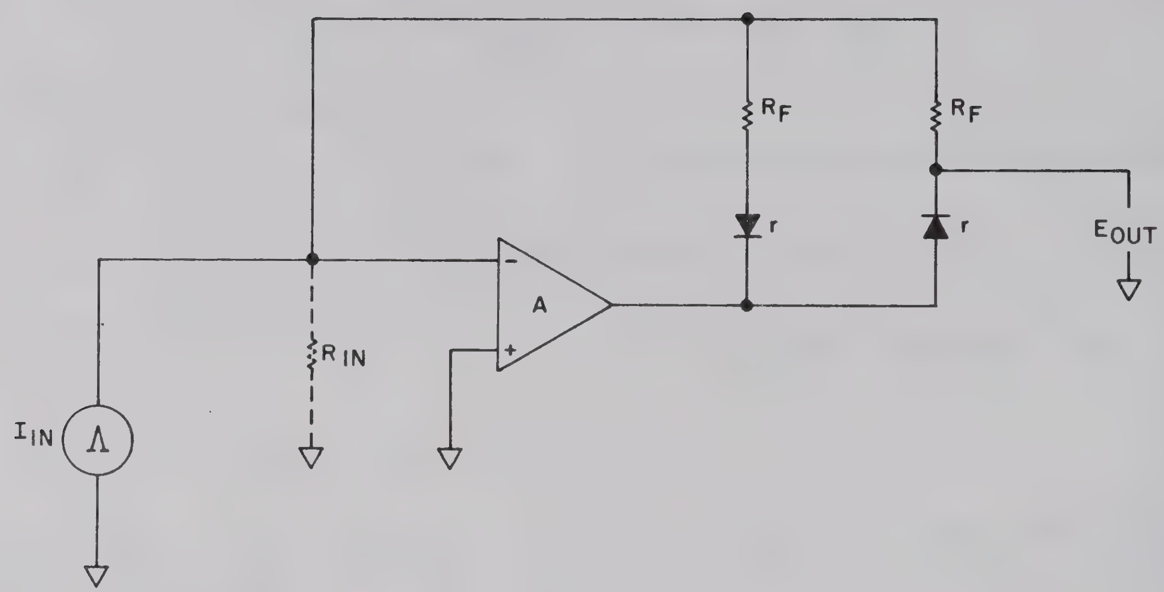

Figure 5-1

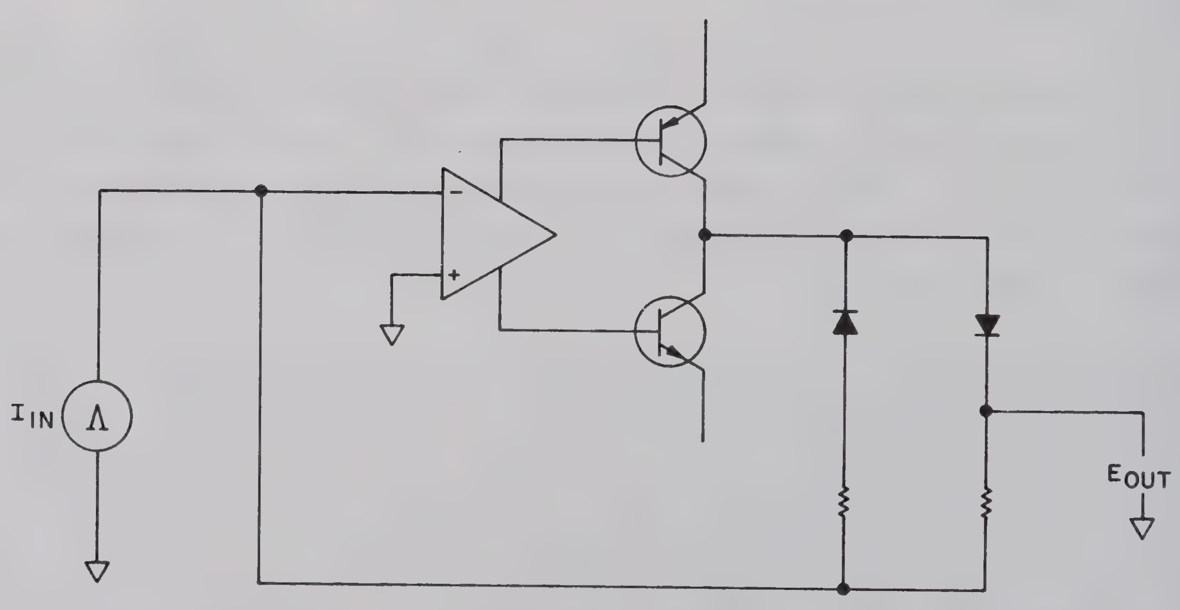

Figure 5-2

In the circuit shown, the stage gain in the absence of signal is very high. However, as either diode conducts, the stage gain decreases and makes stabilization easier. Within the limits of loop gain and amplifier slew rate, the output voltage assumes a value necessary to cause the feedback current to equal the input current. This produces a non-linear voltage waveform at the amplifier output terminal.

The above discussion, of course, applies in general to the idealized circuits shown. Figure 5-3 shows the computer modeled performance characteristics of the actual circuit used in the 82AD. The curves show the output signal polarity reversal indicated above. Various component values and diode types were modeled and the most linear combination used in the final design.

5-2. CALIBRATION METHOD

The calibration method described in the 82AD Instruction Manual produces the most accurate AM indications possible with the 82AD. The method uses the static linearity method outlined previously to determine the ac-to-dc transfer function offset error for two data points on the static curve. The offset determined by this method is the departure of the actual detector system from a straight line transfer characteristic passing through the origin and the first data point. By removing this offset term in the calculation of % AM, the origin of the actual transfer characteristic is shifted to that of the ideal curve.

The method assumes an attenuation standard and a linear digital voltmeter. The equipment specified in the 82AD Instruction Manual is adequate for the method. The Instruction Manual specifies an attenuation of 20.00 dB for the offset calculation which corresponds to 82% AM. However, other attenuations can be used.

The expression for % AM is:

$$\%\ AM = 1.414\ V_{ac}/(V_{dc} - V_o)$$

Taking partial derivatives with respect to the parameters V_{ac}, V_{dc}, and V_o, yields the error sensitivities of each.

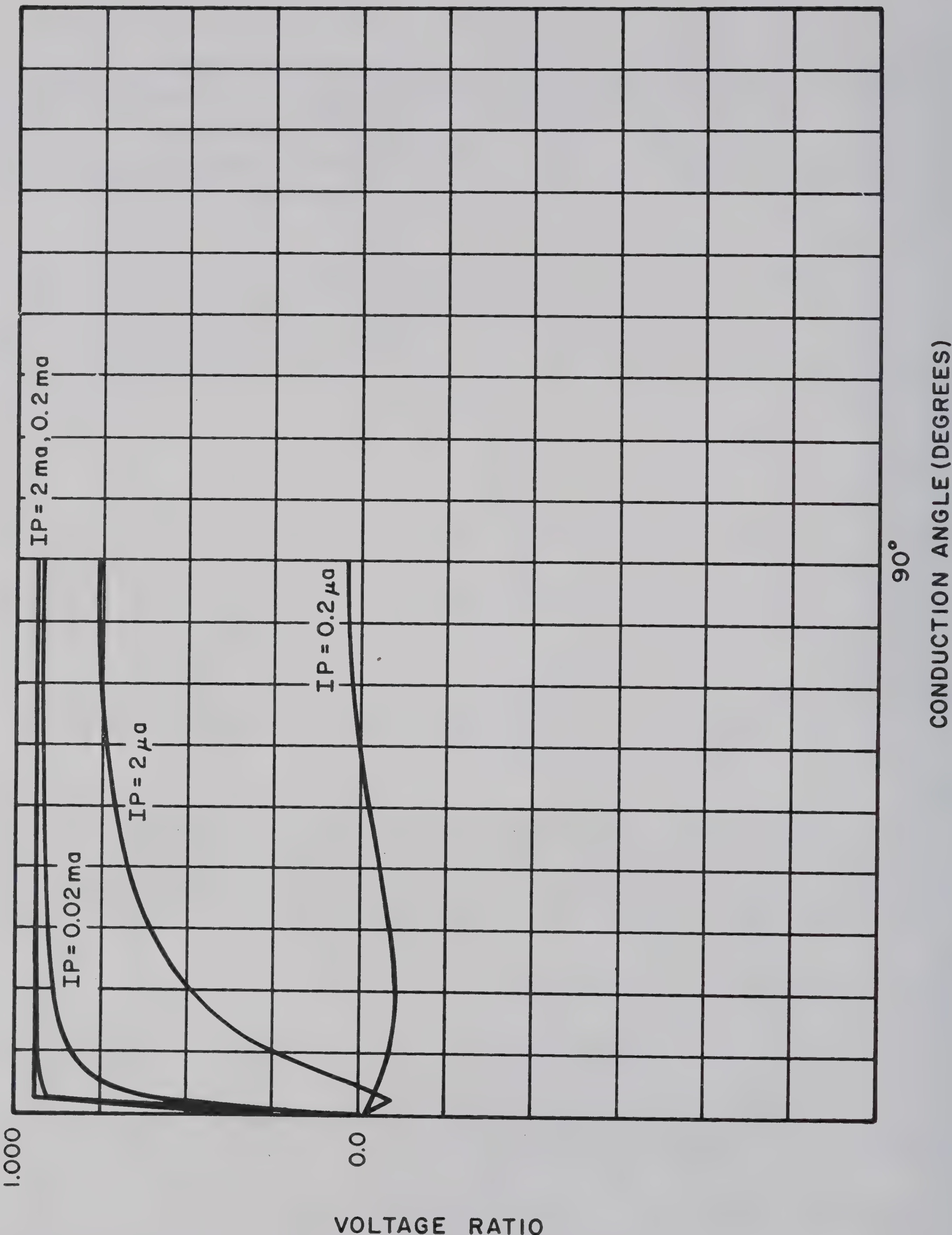
IP = 2 ma, 0.2 ma
IP = 0.02 ma
IP = 2 μa
IP = 0.2 μa
90°
1.000
0.0
CONDUCTION ANGLE (DEGREES)
VOLTAGE RATIO

Figure 5-3

$$S(V_{ac}) = 1.414/(V_{dc} - V_o) \times \text{error in } V_{ac}$$

$$S(V_{dc} - V_o) = 1.414\ V_{ac}/(V_{dc} - V_o)^2 \times \text{error in } V_{dc} - V_o$$

For the specified equipment, the measurement uncertainty is:

V_{ac} : 0.05% at 82% AM

$V_{dc} - V_o$: 0.05% (0.5 mV at 1.000 Vdc)

The error in determining % AM is then the sum of the individual errors, or approximately 0.14% at 84% AM. This error combined with the detector distortion error gives the total AM measurement error (about 0.25% at 82% AM). The 82AD accuracy specification seems conservative in light of these figures. The specification, however, must include the one digit uncertainty of the panel meter and the baseband filter flatness specifications. In any case, at band center, the depth accuracy is normally much better than the specification.

5-3. DERIVATIONS

The following derivation determines the second and third harmonic components of a non-linear transfer function:

$$e_{in} \longrightarrow \boxed{T} \rightarrow e_{out}$$

$$e_{out} = T\ e_{in}$$

for T non-linear:

$$e_{out} = T_1 e_{in} + T_2 e_{in}^{\ 2} + T_3 e_{in}^{\ 3} \quad \cdots\cdots\cdots$$

where

$$T_1 = \left.\frac{d\ e_{out}}{d\ e_{in}}\right|_0 \qquad ;\ \text{slope}$$

$$T_2 = \frac{1}{2!} \frac{d^2 e_{out}}{d e_{in}^2} \Big|_0 \qquad \text{; change of slope}$$

$$T_3 = \frac{1}{3!} \frac{d^3 e_{out}}{d e_{in}^3} \Big|_0 \qquad \text{; change in change of slope}$$

$$e_{out} = \left(\frac{d e_{out}}{d e_{in}}\right) e_{in}$$

$$+ \frac{1}{2!} \left(\frac{d^2 e_{out}}{d e_{in}^2}\right) e_{in}^2$$

$$+ \frac{1}{3!} \left(\frac{d^3 e_{out}}{d e_{in}^3}\right) e_{in}^3$$

for $e_{in} = A \cos\omega t$

$$e_{out} = \frac{d e_{out}}{d e_{in}} (A \cos\omega t)$$

$$+ \frac{1}{2} \frac{d^2 e_{out}}{d e_{in}^2} (A^2 \cos^2\omega t)$$

$$+ \frac{1}{6} \frac{d^3 e_{out}}{d e_{in}^3} (A^3 \cos^3\omega t)$$

$$\cos^2\omega t = \frac{1}{2} (1 + \cos 2\omega t)$$

$$\cos^3\omega t = \frac{1}{4} (\cos 3\omega t - 3\cos\omega t)$$

$\therefore$

$$e_{out} = \frac{d e_{out}}{d e_{in}} (A \cos\omega t)$$

$$+ \frac{1}{2} \frac{d^2 e_{out}}{d e_{in}^2} (1 + \cos 2\omega t) \frac{1}{2}$$

$$+ \frac{1}{6} \frac{d^3 e_{out}}{d e_{in}^3} (\cos 3\omega t - 3\cos\omega t) \frac{1}{4}$$

$$e_{out} = \frac{1}{4} \frac{d^2 e_{out}}{d e_{in}^2} + \frac{d e_{out}}{d e_{in}} (A \cos\omega t) + \frac{1}{8} \frac{d^3 e_{out}}{d e_{in}^3} (A \cos\omega t)$$

$$+ \frac{1}{4} \frac{d^2 e_{out}}{d e_{in}^2} (A \cos 2\omega t)$$

$$+ \frac{1}{24} \frac{d^3 e_{out}}{d e_{in}^3} (A \cos 3\omega t)$$

The following derivation shows the effect of combining second harmonic distortion with a fundamental modulating tone.

Sine related

$$M = A_1 \sin\omega t + A_2 \sin 2\omega t$$

where M = Total signal

A_1 = Amplitude of fundamental

A_2 = Amplitude of 2nd harmonic

since $\sin 2\omega t = 2\sin\omega t \cos\omega t$

$$M = A_1 \sin\omega t + 2A_2 \sin\omega t \cos\omega t$$

integrating

$$\int M = - A_1 \cos\omega t + 2A_2 \left(\frac{1}{2} \sin \omega t\right)$$

evaluating over one cycle

$$\Big|_0^{2\pi} = - A_1 \ (0) + 2A_2 \ (0) = 0$$

Cosine related

$$M = A_1 \sin\omega t + A_2 \cos 2\omega t$$

since

$$\cos 2\omega t = 1 - 2\sin^2\omega t$$

$$M = A_1 \sin\omega t + A_2 (1 - 2\sin^2\omega t)$$

$$= A_1 \sin\omega t + A2 - 2A_2 \sin^2\omega t$$

integrating

$$\int M = - A_1 \cos\omega t + 0 - 2A_2 \left(\frac{1}{2}\omega t - \frac{1}{4} \sin 2\omega t\right)$$

evaluating over one cycle

$$\Big|_0^{2\pi} = 0 - 2\pi A_2 + 0 = - 2\pi A_2$$

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